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CONTINUOUS MEASUREMENTS OF THE VIRTUAL  
HEIGHTS OF THE IONOSPHERE

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## ABSTRACT

This paper is a report of continuous measurements of the virtual heights of the ionized regions of the upper atmosphere. Short pulses of radio-frequency energy are sent out by a transmitter operating on 4,100 kc per second. The time interval required for the pulses to go up to the ionosphere and back is recorded photographically in the same room by means of an oscillograph. The revolving mirror of the oscillograph and the chopper wheel which makes the transmitter pulses are driven on the same shaft by a synchronous motor. Records are shown which indicate the variability especially at night. In the morning and afternoon reflections come from the *F* region showing virtual heights around 240 km. However, during the middle of the day the reflection often splits into two components and the 240-km reflection becomes weak and disappears. The remaining component often rises during the middle of the day to 300 or 320 km and then drops gradually to join the 240-km component which reappears before sunset. Records are given which show the rapid appearance and disappearance of reflection at night from both the *E* and *F* regions. An increase in ionization is probably responsible for the reappearance of *E* reflections of the type shown. However, *F* reflections which gradually become strong at night may possibly be explained by recombination in the lower part of the *F* region which exposes a more strongly ionized upper part. It is pointed out that the changes are so abrupt and irregular that data taken over a longer period and for other frequencies will be necessary before it is possible to establish the relative importance of such things as magnetic storms, meteor showers, sun spots, or thunderstorms.

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## I. INTRODUCTION

This paper is presented as a brief report on experimental results obtained in the measurement of the virtual heights of the ionosphere with a continuous recorder between November 1932 and March 1933. The frequency used was 4,100 kc per second. This work was done at the Bureau of Standards transmitting station near Beltsville, Md. It is desired to show the type of record obtained and to point out the variability from day to day. Results in the past where measurements were made manually have shown the need for continuous records which give a more complete picture of the changes actually occurring.

Briefly, the system used consists of a radio transmitter, receiving set, and galvanometer oscillograph with photographic attachment.



The transmitter is made to send out short pulses of radio-frequency energy at regular intervals by means of a chopper driven by a synchronous motor. Besides the direct path from transmitter to receiver the pulse also may arrive by one or more paths from the ionosphere. The pulses received are passed through the oscillograph and by means of a synchronous revolving mirror the pattern is projected onto the moving photographic paper in such a manner that only the top portion of the pulse is recorded. Since the path length for the direct pulse is fixed it will cause a straight line to be recorded, but as the virtual height of the ionosphere changes the path lengths for the other impulses will change and the corresponding traces will shift with respect to the fixed or "ground" trace. The distance on the record from any trace to the ground trace will be a measure of the virtual height for the corresponding reflection. The system is similar to that described in a previous publication<sup>1</sup> except that in the present arrangement the revolving mirror of the oscillograph and the chopper controlling the transmitter are attached to the same shaft, the transmitting and receiving sets being in the same room. No trouble is experienced with overloading or blocking in the receiving

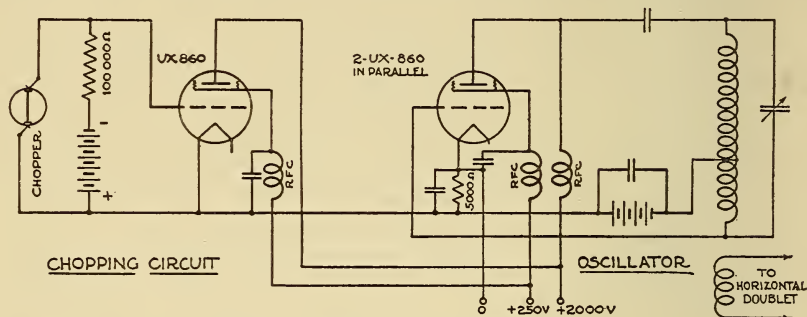


FIGURE 1.—Circuit diagram of transmitter.

Closing of chopper contacts causes plate current to flow in chopping tube. This decreases the negative bias on the oscillator grid so that oscillation takes place.

set from the direct pulse. This consolidation of the apparatus has material advantages of convenience.

The transmitter consists of two 75-watt tubes of the screen-grid type (UX-860) connected in parallel in a Hartley oscillator circuit. A single tube of the same type is connected between the chopper and the oscillator grid circuit to avoid trouble from radio-frequency currents at the chopper contacts (fig. 1). A half-wave horizontal doublet is used for transmitting, while receiving is done with an "L" type antenna.

The receiving equipment consists of a tuned radio-frequency broadcast receiving set preceded by a high-frequency converter. The galvanometer oscillograph element of the fixed magnet type, the moving coil of the dynamic loudspeaker, a copper-oxide rectifier and a 1- $\mu$ f condenser are all connected in series in the output of the receiving set. The condenser, although not essential, serves to sharpen the pulses somewhat, thus giving narrower traces. No shift in the

<sup>1</sup> T. R. Gilliland and G. W. Kenrick, Preliminary Note on an Automatic Recorder Giving a Continuous Height Record of the Kennelly-Heaviside Layer, B. S. Jour. Research, vol. 7, p. 783, November 1931; Proc. I. R. E., vol. 20, p. 54, March 1932.

beginning time of the pulses could be detected with the addition of the condenser so that no change in accuracy of the records should be expected.

Helical gears with a ratio of 16 to 31 are used between the chopper-mirror shaft and the synchronous drive motor, giving slightly over 15 pulses per second. The odd gear ratio is employed to eliminate spurious results caused by noises occurring at power line frequency. The resolution obtained with the slower mirror speed is also more desirable. Recording is done on photographic paper moving at 4 cm per hour. On the vertical scale 1.5 cm represents 100 km in virtual height. Unevenness in the base line of some of the earlier records is caused by irregularities of the chopper brushes, but the virtual height can be measured for any instant by measuring vertically from the ground trace for that time. Since the beginning side of the peaks of the pulse pattern are almost at right angles to the zero-current line the virtual height may be determined by measuring from the lower edge of the ground trace to the lower edge of the reflection trace. It should be kept in mind that with this type of recorder the photographic paper moves in a direction parallel to the axis of the revolving mirror, and perpendicular to the zero current line projected by this mirror. The portion of the pulse pattern recorded was usually below the top of the peaks, so that each trace appears as a double line. Where the trace appears single only the top of the peak is being recorded. The double trace might be mistaken for actual splitting, but the latter phenomenon is so irregular that little confusion should result. A recent improvement has been the substitution of a spherical lens for the conventional cylindrical lens in the oscillograph optical system. By this method the light from a considerable portion of the top part of the peak can be concentrated into a single bright spot on the paper, thus doing away with the double trace. Recording is done with the incandescent oscillograph lamp working at two thirds normal voltage.

Recently other workers have used a gaseous discharge tube in place of the galvanometer oscillograph in the synchronous method of recording.<sup>2,3</sup> Since the speed of response with both types seems to be limited by the radio receiver it appears that the galvanometer oscillograph is at no great disadvantage unless it is desired to sacrifice selectivity. The oscillograph is of assistance when it is desired to monitor reception visually.

## II. RESULTS

The changes that occur at night are the most striking and the extreme variability from night to night makes it impossible to choose any record that can be called typical. In the daytime during the period of these observations reflections on this frequency usually came from the *F* layer<sup>4</sup> showing virtual heights ranging between 220

<sup>2</sup> Rukop and Wolf, Eine leistungsfähige Einrichtung für Messungen an der Heavysideschichten, Zeits. für tech. Phys., vol. 13, p. 132, 1932.

<sup>3</sup> H. R. Mimno and P. H. Wang, New Devices for Recording Kennelly-Heaviside Layer Reflections (abstract), Phys. Rev., vol. 41, p. 395, 1932.

<sup>4</sup> It has been shown that stratification exists in the ionosphere and the region showing virtual heights ordinarily of the order of 100 to 120 km has been called the E layer, while the region giving a virtual height of 200 km or more has been called the *F* layer. This designation was originated by Professor Appleton who first pointed out the existence of stratification. It is likely, in the light of more recent work, that other strata exist at times.

and 320 km. Figure 2 is an example of a record taken during the daytime (Dec. 18). Here the rapid drop is noted in the morning. The trace near the top of the record is a multiple of the first reflection indicating that pulse energy has made two round trips between the ground and the ionosphere. Splitting into two components which has been frequently observed by other workers and attributed to double refraction in the earth's magnetic field is noted at about 0800 and again at 1700 E.S.T. Here the component with the greater retardation is seen to rise and fall rapidly. This phenomenon is more clearly seen in some of the records that follow. At about 1820 the virtual height increases rapidly until the trace moves off scale. The rapid drop in the morning and the rise at night indicated in this record are not observed on all days. Frequently the drop in the morning and more often the rise at night will be gradual. Occasionally reflections continue throughout the night with the virtual height not greater than 500 km. In figure 2 reflections from the *E* layer are noted between 1900 and 2115 E.S.T. giving a virtual height ranging from 120 to 170 km.

In most of the daytime records it is noted that the height is greater at noon than for just after sunrise and before sunset. On some days the records indicate that splitting is occurring and one component ( $F_2$ ) with the longer retardation frequently giving a height of 280 to 320 km becomes predominant near noon while the other component ( $F_1$ ) at 220 to 240 km shows in the morning and afternoon. Occasionally  $F_1$  shows intermittent weak reflections during the middle of the day when  $F_2$  is strong. This is illustrated by figure 3. Figure 4 shows the two components separating at about 0800.  $F_1$  disappears during the middle of the day but reappears at 1400 and joins  $F_2$  at about 1610. It is possible that  $F_2$  is the stronger at times even in the morning and afternoon, but the receiving system cannot resolve it immediately after a very strong  $F_1$  reflection. The virtual heights for  $F_2$  increase during the middle of the day sometimes going as high as 800 km with the peak usually occurring between 1100 and 1300 E.S.T.<sup>5</sup>

Figure 5 shows the momentary appearance of reflection at 0133 on November 30. The virtual height drops rapidly to 370 km, the total time for appearance and disappearance being 10 minutes. Changes after sunrise are noted at the right where the retardation of one component increases and decreases rapidly. Rapid changes of this type are also noted on the morning of January 21 (fig. 10).

Figure 6 shows interesting changes on the evening of December 28. At 1738 reflections begin to appear from a virtual height of 190 km. During the next 15 minutes the height changes to 115 km where it remains for about  $3\frac{1}{4}$  hours except for momentary increases in height at about 1855 and 2030. These increases are practically coincident with appearance of reflections from the *F* layer. At 1855 the *F*-layer reflection is only momentary while at 2030 the time for appearance and disappearance covers about 10 minutes. The *F*-layer ionization is probably present during the entire time but shows only during momentary decreases in *E*-layer ionization.

<sup>5</sup> In a paper now in preparation describing work here on various frequencies, S. S. Kirby, L. V. Berkner, and D. M. Stuart have suggested that splitting of this type is due to stratification in the *F* region and that the high virtual heights of the  $F_2$  component during the day are due to a critical phenomenon in the lower  $F_1$  region much the same as that observed for the *E* layer about 1,000 kc lower in frequency. They have shown that where this critical effect is in evidence on 4,100 kc the virtual heights for  $F_2$  will decrease from the extremely high values as frequency is increased above 4,100 kc.





FIGURE 2.—*Record taken during daytime.*

Note slight increase in height during middle of the day. E-region reflections appear after sunset. All times are United States eastern standard time. All records are for 4,100 kc per second.

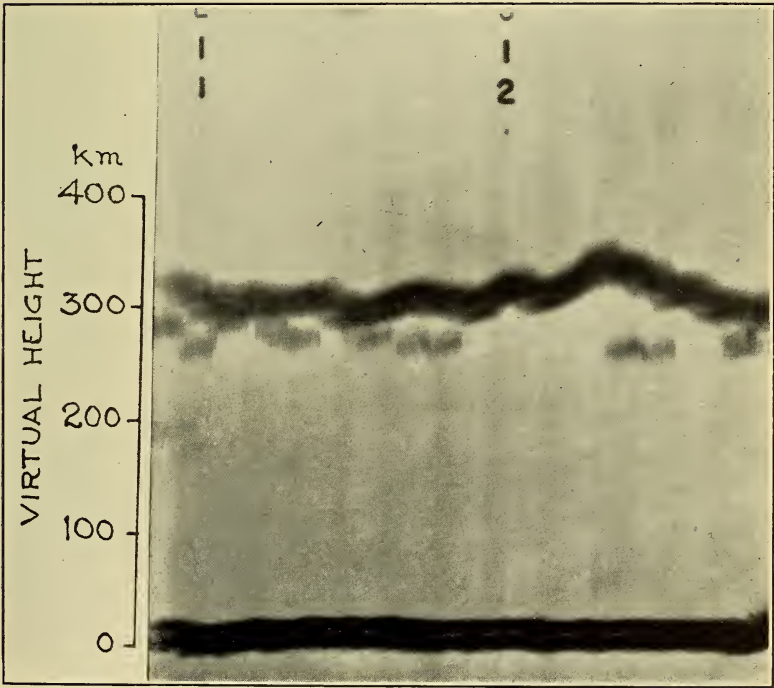


FIGURE 3.—*Record showing two components during the noon hour.*

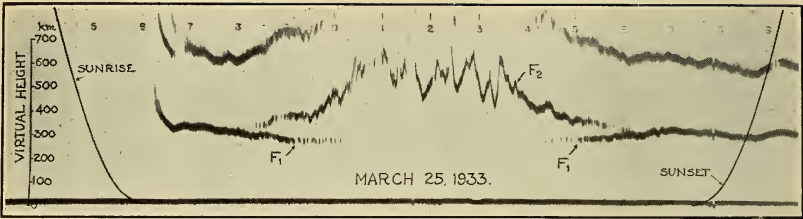


FIGURE 4.—Record showing separation of the two components in the morning and joining again before sunset.

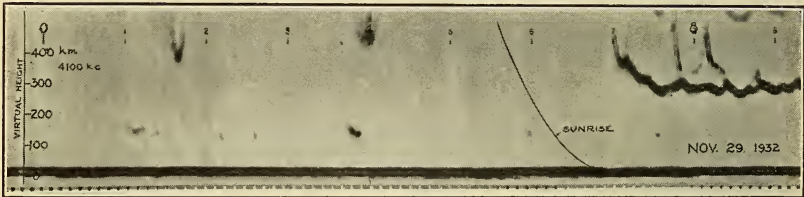


FIGURE 5.—Record showing momentary appearance of reflection at night.  
Also note rapid changes of component with greater retardation after sunrise.

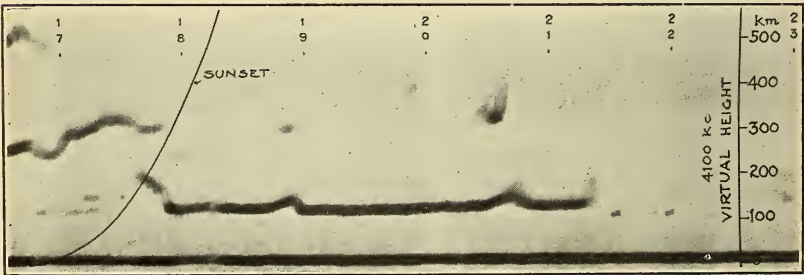


FIGURE 6.—Record showing appearance of F-region reflections coincident with changes in E region.



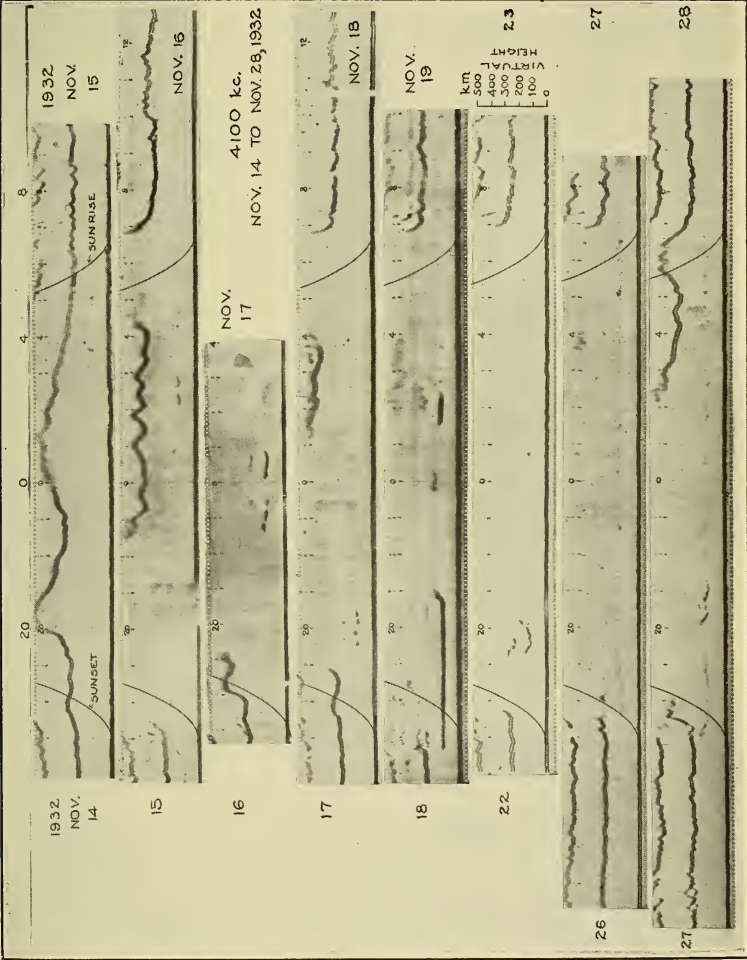


FIGURE 7.—Maximum of Leonid meteor shower occurred on night of November 14-15.

The 14th and 16th are days of magnetic character 1. Record for morning of November 23 shows virtual height decreasing at the rate of 1.1 km per second for 90 seconds. The next record shows still more rapid change.

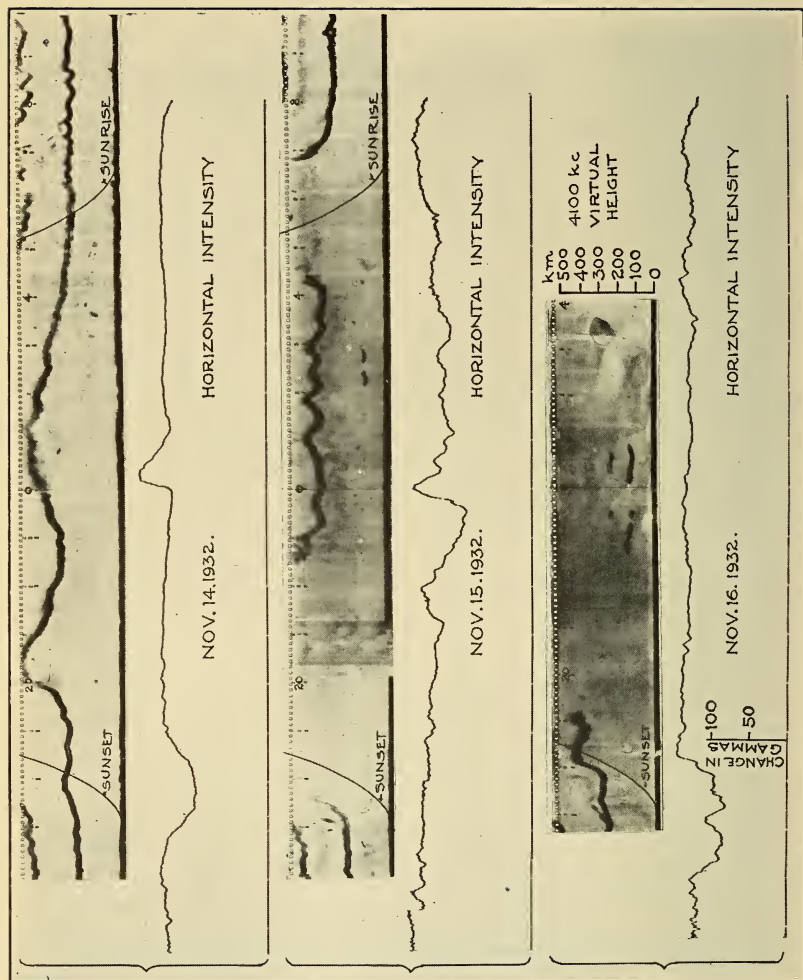


FIGURE 8.—Records of November 14, 15, and 16 replotted with curves of horizontal intensity of earth's magnetic field.

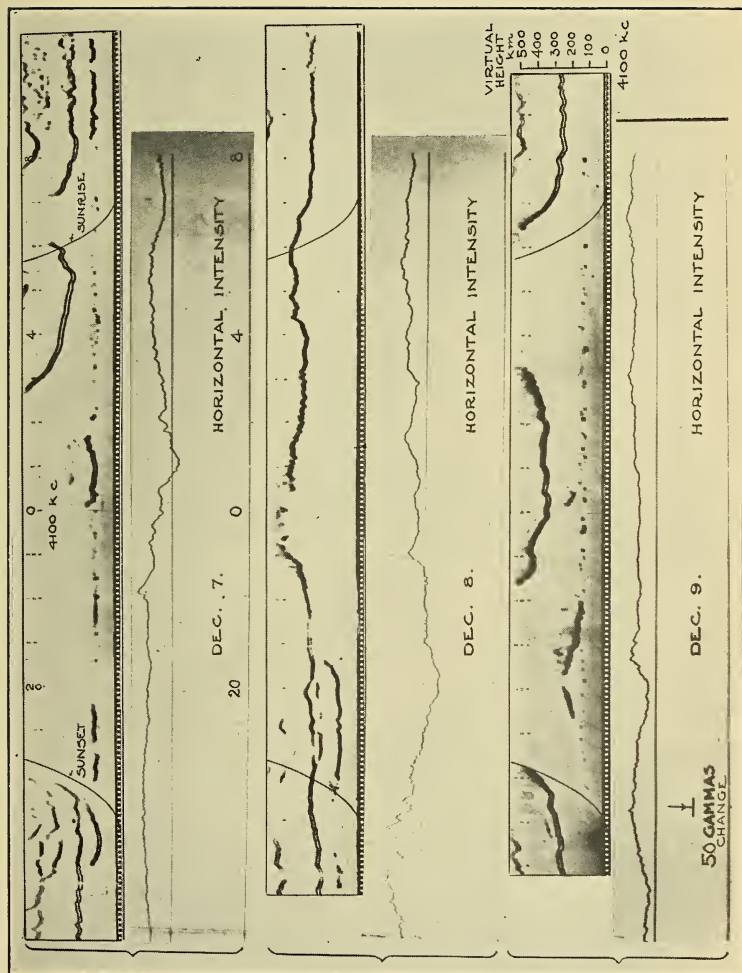


FIGURE 9.—Records for 3 days plotted with magnetic records.

Magnetic storm is indicated by rapid change in horizontal intensity beginning just before 1,600 on the 8th. Note strong reflections at night from both E and F regions.



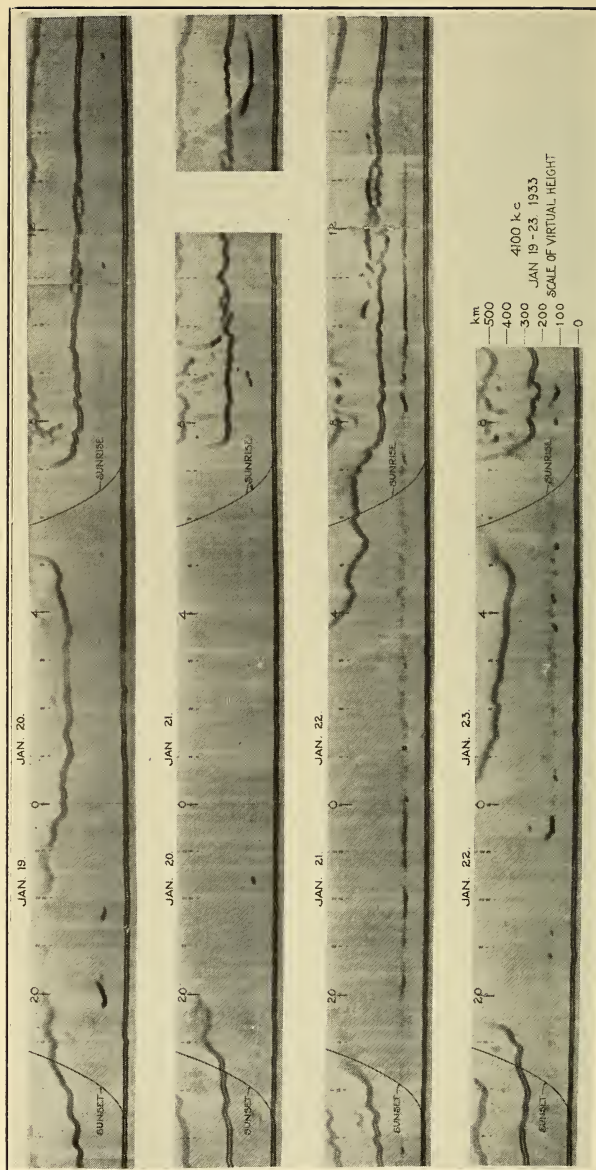


FIGURE 10.—Records for 4 consecutive days.

The 20th and 22d are days of magnetic character 1, while the 19th, 21st, and 23d are zero days.

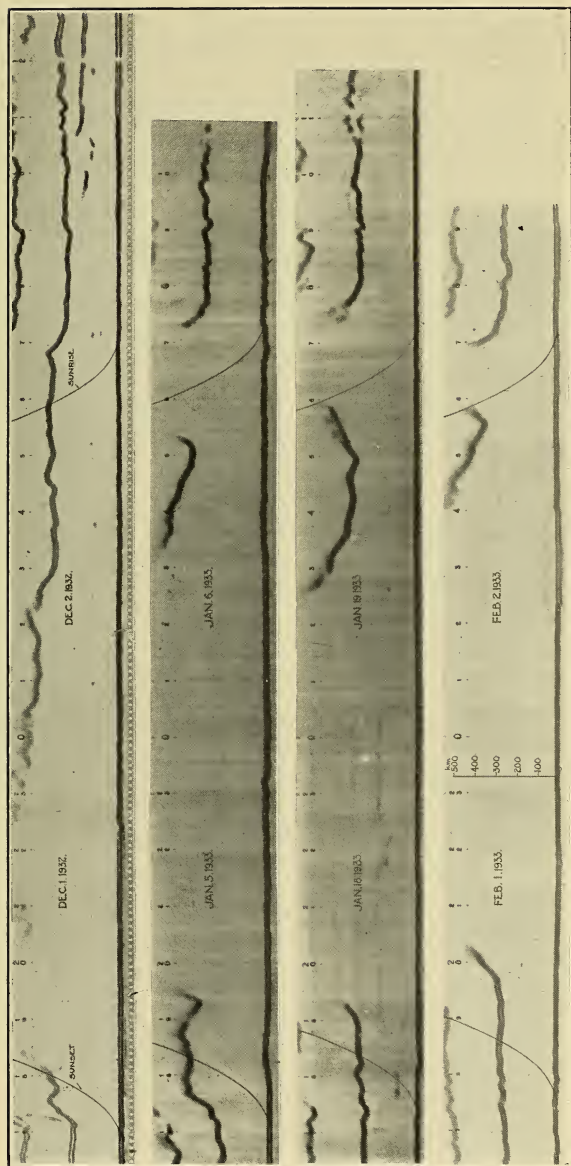


FIGURE 11.—Records showing reflection at night from the upper region without evidence of strong reflections from the lower region. January 6 has magnetic character 1. Others are zero days.

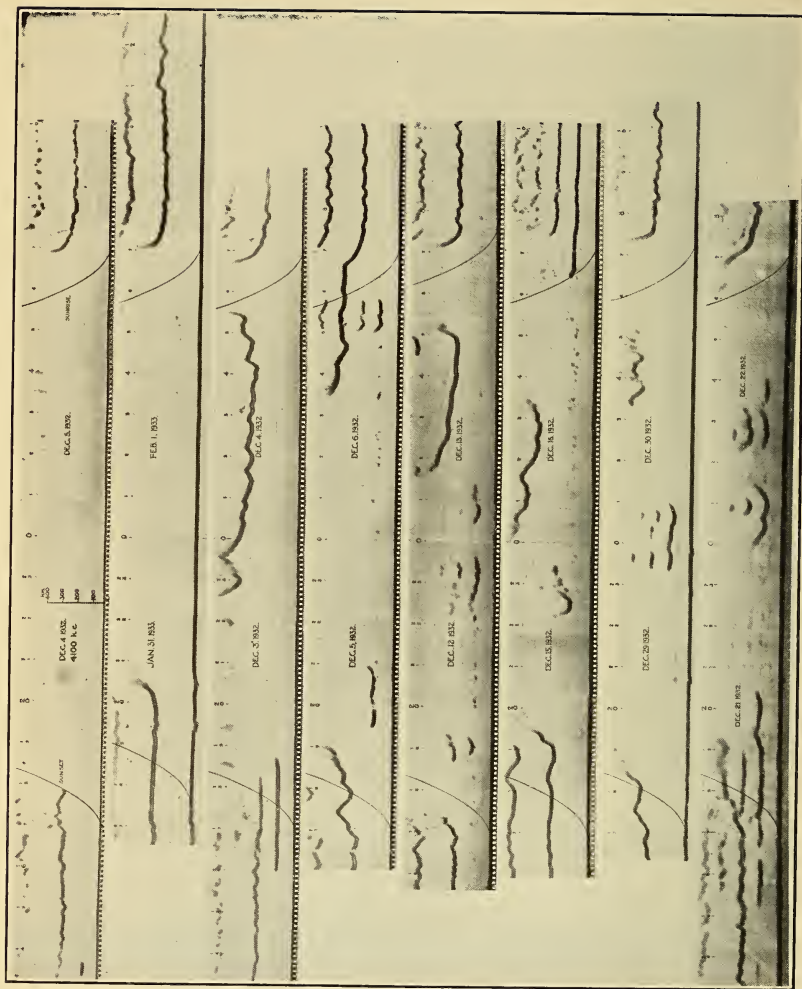


FIGURE 12.—Records chosen to indicate variability from night to night.

The first two records give only slight indication of reflection at night. The third to seventh records inclusive show appearance of both E and F reflections while the last record shows strong reflections from only the E region during the night. December 15 has magnetic character 1. Others are zero days.



Records taken between November 14 and 27, 1932, are shown in figure 7. The 14th and 16th were of magnetic character 1<sup>6</sup>, while the other days of November were zero days. The maximum of the Leonid meteor shower occurred on the 14th. For the purpose of showing the complexity rather than for demonstrating any definite correlation, the records of November 14, 15, and 16 are reproduced in figure 8 with records of horizontal intensity of the earth's magnetic field. The night of November 14-15 was the first during this series that reflections continued throughout the night. Strangely enough there are practically no *E*-layer reflections visible on this record. It is possible that any *E*-layer ionization due to meteors was of such short duration that reflections failed to register. *E*-layer reflections are more in evidence on most other nights. Rapid changes in virtual height on this frequency are most likely to occur at sunrise and sunset, although such changes occur at other times when this frequency is near a critical value. The record for the morning of November 23, (fig. 7) shows the virtual height decreasing at the rate of 1.1 km per second for 90 seconds. The next record shows a much more rapid change but it is impossible to determine the rate of drop accurately because of the slow rate of movement of the film.

Records taken on December 7, 8, and 9 are shown with magnetic records in figure 9. The 7th and 9th are zero days, while the 8th has magnetic character 1. A magnetic storm is indicated by the rapid change in horizontal intensity beginning just before 1600 on the 8th.

Records obtained for four consecutive days from January 19 to January 23 are shown in figure 10. The Cheltenham Observatory gives the 20th and 22d with character 1, while the 19th, 21st, and 23d are zero days.

The changes which have been observed in the ionosphere are so abrupt and irregular that it has been found very difficult to show in just what way they are connected with other phenomena, such as magnetic storms, meteor showers, sunspots, or thunderstorms. It is likely that still other factors will be necessary to explain all the changes observed. It is thought advisable to await the accumulation of data over a longer period of time and on other frequencies in order that a more complete study may be made.

The reappearance of reflections at night suggests an increase in ionization, especially where strong reflections from the *E*-layer suddenly occur. The first record of figure 9 shows a strong *E* reflection beginning just after midnight and lasting until about 0200. At 0245 reflections appear from the upper region. Although these latter reflections may be explained by changing of the gradient of ionization in the *F* layer, as mentioned below, it is possible that ionization has merely passed through the *E*-layer critical value for the frequency used and long retardation and high absorption are occurring between the disappearance of the lower reflection and the appearance of the higher one. Another critical value is reached about 0600 and long retardation again occurs. At shortly after 0700 reflections again appear with sunrise. This occurs again on the third record earlier in the night.

Schafer and Goodall<sup>7</sup> have noted the reappearance of reflections at night from the *E* layer. They mention that a changing gradient

<sup>6</sup> Zero magnetic character indicates quiet day, no. 1, moderately disturbed, and no. 2, severely disturbed. Magnetic records supplied by the Cheltenham (Md.) Observatory of the Coast and Geodetic Survey.

<sup>7</sup> J. P. Schafer and W. M. Goodall, Kennelly-Heaviside layer studies employing a rapid method of virtual height determination, *Proc.I.R.E.*, vol. 20, p. 1131, July 1932.

of ionization may explain this reappearance, but they believe that an increase in ionization is more likely. The latter viewpoint would be supported by changes of the type shown in the first and third records of figure 9, where the appearance of strong reflections is sudden. In figure 11 are four records showing reflections at night from the upper layer without evidence of strong reflections from the lower layer. Here an increase in ionization may not be occurring. Possibly as recombination begins after sunset a critical value is reached in the lower part of the F layer so that high absorption and long retardation result. However, as recombination proceeds farther an upper, more richly ionized part of this region, where recombination is less rapid, begins to return energy. As conditions get farther from the critical value the virtual height is frequently seen to be as low as 280 km. The ionization in this upper region appears to reach another critical value just before sunrise.

Figure 12 contains records chosen to indicate the variability from night to night. The first two records give only slight indication of reflections at night. Note the rapid opening and closing of the split reflection at 1700 on the first record. The third to seventh records inclusive show appearance of reflections from both E and F layers, while the last record shows strong reflections from only the E layer during the night.

### III. CONCLUSIONS

Of greatest interest perhaps is the reappearance of strong reflections at night from both E and F layers. Some of these reflections indicate sudden increases in ionization, while others suggest that recombination in a lower part of the region exposes the upper part where ionization is richer.

Many of the changes observed are very sudden, and strong reflections from the E layer may appear at almost any hour. Various explanations have been offered in the past, including sun spots, meteor showers, and thunderstorms. Comparisons are also made between such results and changes in the earth's magnetic field. Although certain peculiarities, such as strong E reflections, are observed at magnetically disturbed times quite similar phenomena are observed when no unusual magnetic changes are in evidence. Since the changes in the ionosphere are so frequent and so rapid it is impossible, with the small amount of data at hand, to show definitely just how important each factor is.

None of the explanations yet offered seems to explain satisfactorily the extremely high ionization frequently observed at night. Although E-layer reflections appear at almost any time, they occur most frequently around the time of sunset or shortly after on this frequency during the period of these observations.

This method offers a convenient means for studying the physical properties of the upper atmosphere and should prove helpful in the solution of certain radio transmission problems. With data of this type taken over a longer period and on other frequencies it is hoped that it will be possible to obtain a more exact picture of the changes which occur in the ionosphere and to determine some of the agencies responsible for these changes.

WASHINGTON, April 18, 1933.





